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FOREST PEST MANAGEMENT
Pacific Southwest Region

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Progress Report: Effects of Subsoiling Study, Milford Ranger District, Plumas National Forest

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Background

Subsoiling is becoming a standard practice to alleviate detrimental soil compaction following biomass harvesting in eastside pine and mixed conifer forests in California. Compaction of soil following the harvesting can be detrimental to growth of residuals, to establishment of natural regeneration, and may change long term soil productivity. The short and long term effects of this subsoiling practice on forest soil biodiversity and forest ecosystem function as a whole is not known. Because of wounding of tree boles and roots associated with subsoiling, some long term detrimental effects may occur. Several Forest Pest Management biological evaluations (Kliejunas 1992, Pronos and Wenz 1992) suggested that only through monitoring could the effects be determined. In order to evaluate the impacts of subsoiling on root pathogens, insect vectors of root pathogens, and tree growth, Forest Pest Management, in cooperation with the Pacific Southwest Research Station and the Southern Research Station, initiated a long term study on the Milford District, Plumas National Forest in 1993 to monitor these effects.

The objectives of the study were to:

1. Determine if subsoiling is associated with increased incidence of root disease (black stain or annosus) infection in residual trees.
2. Determine if beetle vectors of black stain root disease are more attracted to areas subsoiled than to areas without subsoiling.
3. Determine effects of subsoiling on physiological processes in residual trees and on soil processes that affect long term site productivity.

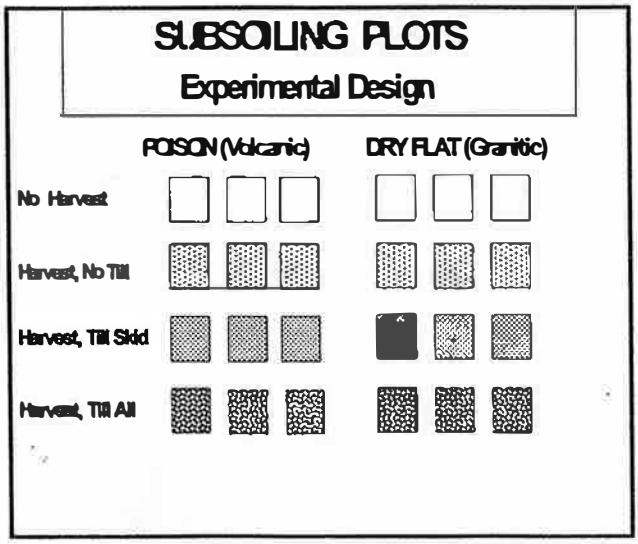
In addition, the Institute for Tree Root Biology (USDA Forest Service, Southern Research Station, Athens) utilized the study plots to:

1. Determine activities of sucrolytic and glycolytic enzymes and their possible utility in assessment of tree response with respect to stand treatments, and
2. Conduct an exploratory study on the effects of treatments on live soil fungal biomass.
3. Determine root health in relation to subsoiling treatments.

Results of the root excavation and enzymatic activity studies have been reported (Otrosina et al. 1996).

The Experimental Design

In June 1993, plots were established on each of two sites, Poison and Dry Flat, on the Milford Ranger District, Plumas National Forest. The sites support stands of 88-to 114-year-old Jeffrey pine. Poison was located on volcanically derived soil (Sattley complex, characterized by a loam surface layer over a clay loam subsoil), with an effective rooting depth of 35 to 50 inches. Dry Flat was located on granitic soil (Toem-Cagwin complex, characterized by loamy sand surface texture and a coarse sand loam or coarse loamy sand subsoil), with an effective rooting depth of 20 to 30 inches.



Within each site, 12 contiguous 300 ft (1 hectare) plots, consisting of four randomly assigned treatments replicated three times, were established. The four treatments were: (1) no thinning and no subsoiling (control), (2) thinning, without subsoiling, (3) thinning, and subsoiling skid trails only, and (4) thinning, followed by subsoiling the entire plot to a depth of 50 cm. With the exception of the controls, the plots were whole tree harvested in August of 1993. The thinning

removed approximately 50% of the basal area of each plot. The Poison plots were subsoiled in August 1993, and the Dry Flat plots were subsoiled in September 1993. In the treatment involving subsoiling the entire plot, at least 80% of the plot area was traversed by the subsoiling implement, based on visual estimates of disturbed soil surface. For the purpose of the study, only treatments 1, 2, and 4 were subjected to further analysis and observations. Site locations and plot treatment assignments at the two sites are described in the Appendix.

At the time the study was established, the following measurements were planned:

1) soil bulk density — subsoiled vs. not, at pre-determined locations
2) soil strength — subsoiled vs. not, at pre-determined locations
3) soil moisture — subsoiled vs. not, at pre-determined locations
4) tree growth — on selected trees in each treatment, measure species, dbh, total height, live crown length, signs of damage, and surrounding basal area; repeat after 5 years
5) crown symptoms - on same trees that growth measurements were taken
6) Lindgren flight traps, sampled weekly throughout the flight season; for 2 years
7) 3 to 5 years after treatment, trench with backhoe to estimate amounts of mechanical injury to roots and root disease infection
8) changes in tree physiological processes

Results to Date

Soil measurements: Soil bulk density information was collected by Wayne Johannson, soil scientist, in May 1994. Johannson's examination of the sites suggested to him that an inappropriate implement (broad and blunt shank and wing design which forced soil and roots up and out of the furrow as the tool was pulled, rather than lifting and shattering) was used, and it was not representative of acceptable subsoiling. Johannson suggested that the treatment was "tillage" (cultivating or mixing the soil to a shallow depth) rather than "subsoiling" (loosening of the soil with narrow tools below the depth of normal tillage without inversion and a minimum mixing of the soil). Because of the disruption to the soil profile caused by the inappropriate implement, Johannson cautioned that a valid assessment of subsoiling is not possible, and interpretation of subsequent monitoring results needs to consider the excessive soil disruption.

Soil core samples were collected from each of the two sites during May 1994 at depths of 10 cm and 30 cm. Within each of the harvest only and harvest/skid trails tilled plots, soil cores were collected from three randomly selected locations, representative of the applied treatment. Soil cores from the undisturbed plots were collected from a location in each plot. In each of the no harvest plots, soil cores were collected at one location. Computations of bulk density were performed using the BDEN program. The bulk density values were converted to the Region 5 porosity scale to allow for comparison with the R-5 Soil Quality Standard (SQS) for soil porosity. The standard allows for a 10% reduction in total soil porosity over undisturbed conditions. This threshold bulk density is

used to compare the measured bulk densities to evaluate whether detrimental soil compaction has occurred or exists. The results are presented in tabular format in Table 1.

Table 1. Bulk density values (g/cm^3) at Dry Flat and Poison sites.

Treatment	Dry Flat		Poison	
	Sample Depth		Sample Depth	
	10 cm	30 cm	10 cm	30 cm
Undisturbed	1.25 ± 0.10	1.28 ± 0.09	1.12 ± 0.01	1.18 ± 0.09
Threshold	1.39	1.42	1.27	1.33
Skid Trail	1.42 ± 0.06	1.43 ± 0.06	1.34 ± 0.08	1.30 ± 0.09
Tilled Trail	1.31 ± 0.09	1.44 ± 0.07	0.99 ± 0.08	0.97 ± 0.17

At Dry Flat, the coarse grained granitic soils were compacted. Compaction of the skid trails exceeded the threshold values for detrimental compaction. The tillage reduced the near surface skid trail densities from a mean of 1.42 g/cm^3 to 1.31 g/cm^3. Tillage was effective at reducing or mitigating about two-thirds of the induced compaction. The tillage was ineffective at the 30 cm depth and resulted in no reduction of compaction.

At Poison, the undisturbed bulk densities were 1.12 g/cm^3 at 10 cm and 1.18 g/cm^3 at 30 cm., with the threshold bulk densities being 1.27 g/cm^3 at 10 cm and 1.33 g/cm^3 at 30 cm. The measured values for compaction of the skid trails at the 10 cm depth exceeded the threshold values for detrimental compaction. The tillage reduced skid trail densities below that of the undisturbed locations.

Tree measurements: After harvesting, trees in 1/10 acre circular plots, located by a stake in the center of treated and control plots at each site, were tagged. Measurements (tree dbh, total height, live crown ratio, signs of damage, and surrounding basal area) were taken. These baseline data will be compared with measurements taken in 1997, and in 2002.

Root diseases: Before harvesting, but after plot boundary establishment, the Dry Flat and Poison sites were surveyed to determine incidence and location of any black stain or annosus root disease activity. In areas where black stain root disease, caused by the fungus *Leptographium wageneri*, is present, soil and root disturbance may attract root-feeding beetles that are vectors of the disease. Bole and root wounding may increase incidence of annosus root disease, caused by *Heterobasidion annosum*.

Black stain root disease was not observed in or near either Dry Flat or Poison. The nearest known location of black stain is about 40 miles northwest, in the Poison Lake, McCoy Flat area, on the Lassen National Forest.

Evidence of annosus root disease was found at Poison and at Dry Flat. The Poison site had only a very few, old Jeffrey pine stumps. Conks and signs of *H. annosum* were found in one stump at plot 1, with no signs of root disease activity (recent or old dead saplings or poles) around it. At the Dry Flat site, annosus activity was present in plots 3, 4, 5, 6, 11 and 12. Activity consisted of annosus conks and decay in Jeffrey pine stumps with fading, recently dead, or old dead Jeffrey pine saplings or poles adjacent. The locations within each plot were mapped.

Insect trapping: Lindgren flight traps were sampled weekly throughout the flight season, for 2 years. Few putative black stain vector beetles were caught. There was no evidence of increased bark beetle activity due to the treatments.

Root excavation: Trenches were dug with a backhoe around selected trees in a preliminary August 1994 trial. A significant amount of root damage in the tilled plots, as expressed by percentage of root dieback, was observed. Tilled plots had extensive dieback (25 to 30 cm) in roots less than 1 cm in diameter. The percentage of roots less than 1 cm that exhibited dieback was significantly greater in the tilled plots (27.6 ± 4.4%) versus the undisturbed control plots (9.1 ± 3.9%). Root dieback in thinned only plots ((17.7 ± 3.9%) was not significantly different from the subsoiled (tilled) or control (undisturbed) plots.

In 1995, 2 meter-wide trenches were dug about 1.5 meters from each of two randomly selected dominant or co-dominant trees in each treatment plot at the Poison and Dry Flat sites. The total number of roots less than 1 cm in diameter counted in the sampling quadrangles differed by site (Poison - 53.2 ± 4.0; Dry Flat - 34.8 ± 4.0), but not by treatment or by interaction among site and treatment. No significant differences were found between sites or treatments for number of roots greater 1 cm and depth of rooting zone in the excavated trees.

The Poison site tended to have roots concentrated in the upper 30 cm of the soil profile, while the Dry Flat site tended to have rooting depths at least twice as deep. This may have a bearing on impact of subsoiling on tree response to damage from the subsoiling.

Sucrose metabolizing enzymes: Tree cambial sucrolytic and glycolytic enzymes are known to be sensitive to tree stress and time of year in several species (Sung et al 1989, Sung et al. 1993). These enzymes had not previously been studied in Jeffrey pine. In order to determine activities of these enzymes [sucrose synthase (SS), pyrophosphate dependent phosphofructokinase (PPi-PFK), and ATP-dependent phosphofructokinase (ATP-PFK)] and their possible utility in assessment of tree response with respect to stand treatments, cambial tissue from Jeffrey pine were collected and analyzed. Cambial samples were obtained from each of two selected dominant or co-dominant Jeffrey pine on plots in July 1994, October 1994, June 1995, August 1995, and September 1995. All tissues were

processed for enzyme analysis within 72 hours of collection, using techniques developed for loblolly pine seedlings (Sung et al. 1993).

No relationship between treatments, sites, or tree dbh was found for stem cambial SS activity. Activities of PPI-PFK and ATP-PFK were also not related to treatment or site. However, there was a strong seasonal relationship for SS activity. In loblolly pine, SS activity is related to sucrose-sink relationships in carbon metabolism and is strongly correlated with growing season conditions. The patterns of SS activity for Jeffrey pine on these sites suggest a narrow window available for growth compared to that of loblolly pine. The Dry Flat site seems to support greater and longer growth activity for Jeffrey pine than the Poison site (Otrosina et al. 1996).

Fine root samples and ergosterol analysis: Fine roots were collected by sampling soil to a depth of approximately 20 cm under the drip line of the trees selected for enzyme samples. One and two trees per plot were sampled in August and September, 1995 respectively. Ergosterol extraction and detection procedures were modified from those of Sung et al. (1995).

Significant differences were found between sites, treatments, and month of sample for ergosterol content. Because ergosterol is present only in fungal cell membranes, its analysis provides a measure of living fungal biomass. The subsoiled (tilled) plots, which generally had considerable soil displacement associated with the path of the subsoiling implement, had higher ergosterol content relative to the other treatments. This displacement may have provided additional substrate for fungi decomposing severed fine roots and thus given a higher ergosterol content. It is also possible that subsoiling may have in some way increased ectomycorrhizal development by stimulation of fine root production. Additional studies are need to provide an answer. An explanation for the higher ergosterol found in the August samples may be the drier soil environment that existed in September (Otrosina et al. 1996).

Summary

The effects of subsoiling versus consequences of soil compaction on the health and growth of trees in these stands must await long term follow up of this study and establishment of new, additional experiments that address variables such as soil type and site quality. Obtaining information on interactions between various forest management regimes and soil fungal biomass, fine root turnover, physiological processes, and pathological relationships relative to effects on tree growth is essential for evaluation of site treatment efficacy.

Literature Cited

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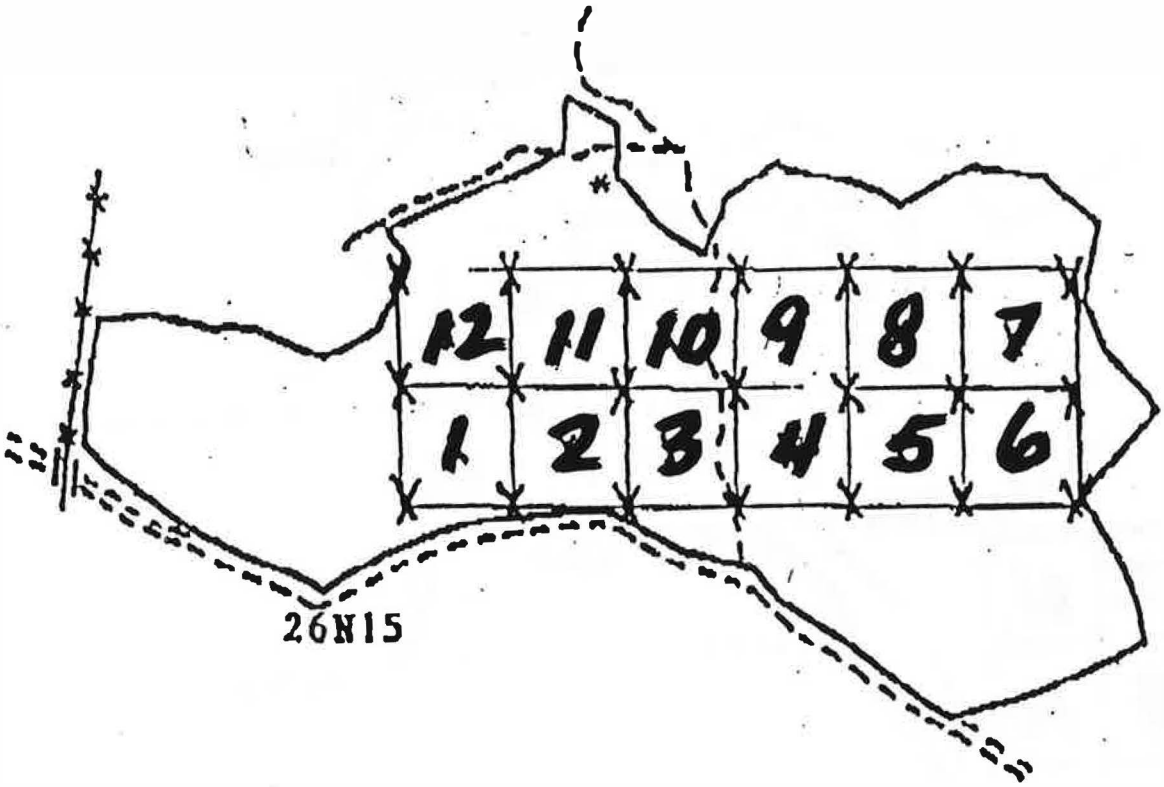
PLOT TREATMENTS, MILFORD SUBSOILING STUDY

Treatment	Plot Number	
	Volcanic Soil	Granitic Soil
subsoil, entire plot, Rep 1	2	11
subsoil, entire plot, Rep 2	6	2
subsoil, entire plot, Rep 3	10	7
subsoil, skid only, Rep 1	9	1
subsoil, skid only, Rep 2	3	6
subsoil, skid only, Rep 3	7	8
no subsoiling, Rep 1	1	12
no subsoiling, Rep 2	4	4
no subsoiling, Rep 3	11	10
no harvesting, Rep 1	8	3
no harvesting, Rep 2	5	5
no harvesting, Rep 3	12	9

POISON THINNING
T.26.N R.13.E Sec. 10,15
Block 03-35
56 Ac.



10
15

DRY FLAT THINNING
T26N, R13EN Sec. 5,6
T27N, R13E, Sec.31,32
Block 517-20 Fy 92
80 Ac